An Automatic Device for the Assessment of Cardiovascular Autonomic Function

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Autonomic neuropathy is a common complication of diabetes mellitus and is associated with significant morbidity and possibly an increase in mortality. Despite this, however, autonomic dysfunction is not usually sought in the routine assessment of diabetic patients. We report the development and testing of a small, portable and reliable device that allows the routine testing of cardiac autonomic function in the outpatient setting with minimal inconvenience to the patient. This should facilitate the accurate assessment both of patients with symptoms suggestive of autonomic dysfunction and of autonomic function in research. © 1998 John Wiley & Sons, Ltd.

***Diabet. Med.* 15: 700–704 (1998)**

KEY WORDS **autonomic neuropathy; portable testing device; heart rate variability**

Received 3 October 1997; revised 22 December 1997; accepted 15 March 1998

Introduction

Autonomic neuropathy in diabetic patients may be associated with an increase in mortality rate[1–3] but autonomic dysfunction is seldom sought in routine clincal practice. A variety of methods have been used to detect cardiac autonomic neuropathy, including heart rate variability from 24-h Holter recordings[4] and spectral analysis of short segments of heart rate data.[5] The heart rate variability tests described by Ewing and Clarke[1,6] are the most widely used in the assessment of cardiac autonomic neuropathy. To perform these tests, ECG recordings are analysed to find the maximum and minimum heart rates in response to respiration, postural change and the Valsalva manoeuvre. Analysis of ECG recordings is time consuming, leading to delays in providing test results and reluctance to make the assessment. The accuracy of visual interpretation is also limited.

Description of the Device

We present an autonomic neuropathy tester (ANT) made, developed and assessed by the Medical Physics Department of Leicester Royal Infirmary. The device was designed to automate the acquisition of R–R interval data for heart rate variability tests, to eliminate visual chart analysis and reduce measurement errors. The device is a pocket-size, battery powered unit (Figure 1), designed for use in an outpatient clinic. It derives R–R interval measurements from wrist electrodes, minimizing patient preparation time.

To improve consistency of testing, instructions and timing information for the operator are given via a front panel liquid crystal display (LCD) while an array of light emitting diodes (LED), illuminated in sequence at the rear, indicates to the patient when to breathe in and out during the respiration test. Following the completion of each test, the stored R–R interval measurements are transferred to a portable computer for analysis. Operation of the system is controlled by a microprocessor, a counter/timer circuit (CTC) and peripheral input/output ports in the same package. Operating instructions, heart rate and test results are displayed on an LCD, on the front of the device. The 6 LEDs, indicating to the subject when to breathe in and out in the inspiration/expiration test, are on the back panel. Input commands, to select a test, to start acquisition of the heart rate data or to output the results, are selected via controls on the front panel (Figure 1).

Following completion of each heart rate variability test, R–R interval data are transferred via an optically isolated serial link to a portable personal computer for display and analysis. The maximum and minimum heart rate values required from each test to calculate the heart rate variability ratios are readily identified from a heart rate trend display (Figure 2), in conjunction with a table of values of heart rate measurements.

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CCC 0742–3071/98/080700–05$17.50

Figure 1. The ANT device

Testing the Device

Accuracy of R–R Interval Measurements

To assess the accuracy of the device measurements of R–R intervals, during 3 tests on each of 5 volunteers, were recorded simultaneously with the ANT and a standard ECG recorder. Results were compared using the method of Bland and Altman.[7] For the data sets, the 95 % confidence levels for the differences between readings were within ± 20 ms, which corresponds to ± 0.5 divisions of the ECG chart paper with a chart speed of 25 mm s^{-1} and 1 mm divisions.

The accuracy of ANT R–R interval measurements and chart measurements were also compared using 14 known simulated heart rates, using an HP3325A precision signal generator (Hewlett Packard Co., Idaho, USA), in the range 48 to 126 beats per minute. The upper and lower 95 % confidence limits for the chart measurements were ± 19 ms, equivalent to approximately ± 0.5 divisions of the chart paper. The corresponding confidence limits for the ANT measurements were 1.9 ms and −2.5 ms, respectively, consistent with the temporal precision of the device which is determined by the microprocessor interrupts at 2 ms. These measurements imply that the differences between the two techniques observed with real ECG signals were due mainly to random errors in interpretation of the ECG charts and that R–R interval measurements using the ANT can be up to 10 times more accurate. At high heart rates, the uncertainties in R–R interval derived from ECG charts could be significant in the measurement of heart rate variability.

Accuracy of Heart Rate Ratio Measurements

Values of heart rate variability ratio derived from the trend display of ANT measurements were compared with corresponding values derived by manual analysis from simultaneous ECG chart recordings for sets of 3 tests conducted in 22 diabetic subjects attending a routine diabetic clinic. The measurements were compared using the method of Bland and Altman.[7] The 95 % confidence limits for the differences in ratio values ranged from ± 0.048 for the respiration tests to ± 0.09 for the Valsalva tests (Figure 3). The corresponding mean values of heart rate ratio were 1.27 and 1.68.

The differences in ratio values arose mainly from inappropriate selection of maximum or minnimum R–R intervals from the ECG charts. Selection from the ECG chart was most difficult when heart rate variability was low. In the standing test, values near the 15th and 30th beats, respectively, following the stand were chosen from the ECG chart as suggested by Ewing and Clark.[1] The heart rate trend display of ANT measurements allowed rapid and positive identification of maxima and minima and demonstrated that in the standing test, these did not always occur near the 15th and 30th beats.

Reliability of R-wave Detection

Reliability of R-wave detection by the ANT was assessed by inspecting the heart rate trend on display on the PC for outlying values. This procedure was carried out for sets of 3 tests conducted on each of 71 subjects, 45 of whom were randomly selected diabetic patients attending the clinic for routine visits, the remainder being non-diabetic subjects attending other medical clinics. These were different patients from those studied in the previous section. Muscle noise and movement artefact during the standing phase of the standing test were excluded from this analysis. Software error checking is within the ANT. If errors are detected, the user is alerted via the front display. In addition, it is easy to see from the graphs (Figure 2) if any beats are incorrectly detected.

The respiration and standing tests showed a low

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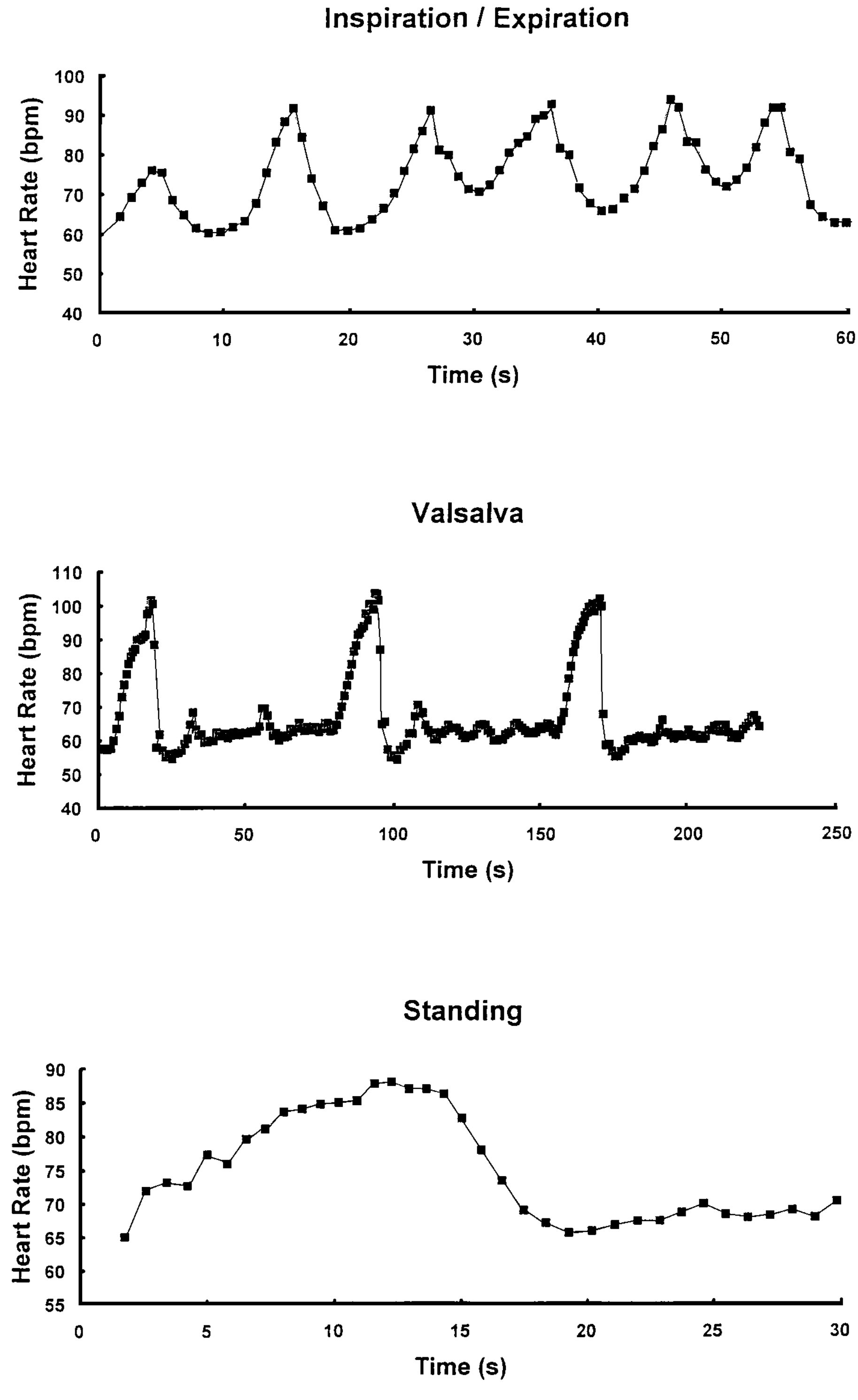

Figure 2. The graphical data of the three heart rate variability tests

incidence of outlying values. Of 213 data sets, each containing approximately 85 R–R intervals, 9 showed a single outlying point, each of which was associated with a low signal to noise ratio. R-wave detection errors were more common in the Valsalva test data due to muscle noise and movement artefact resulting from the stress of the test. Of 71 data sets, 33 showed heart rate values outside the trend, usually due to movement, but these points were easily identified and excluded from analysis of the ANT data. Six of the diabetic subjects had symptoms of autonomic neuropathy (postural hypotension and diarrhoea) and the ANT accurately measured heart rate changes in those patients.

Immunity to Noise, Ectopic Beats, and Cardiac Arrhythmia

The ability of the ANT to detect or reject noise, ectopic beats, and cardiac arrhythmia was assessed by applying

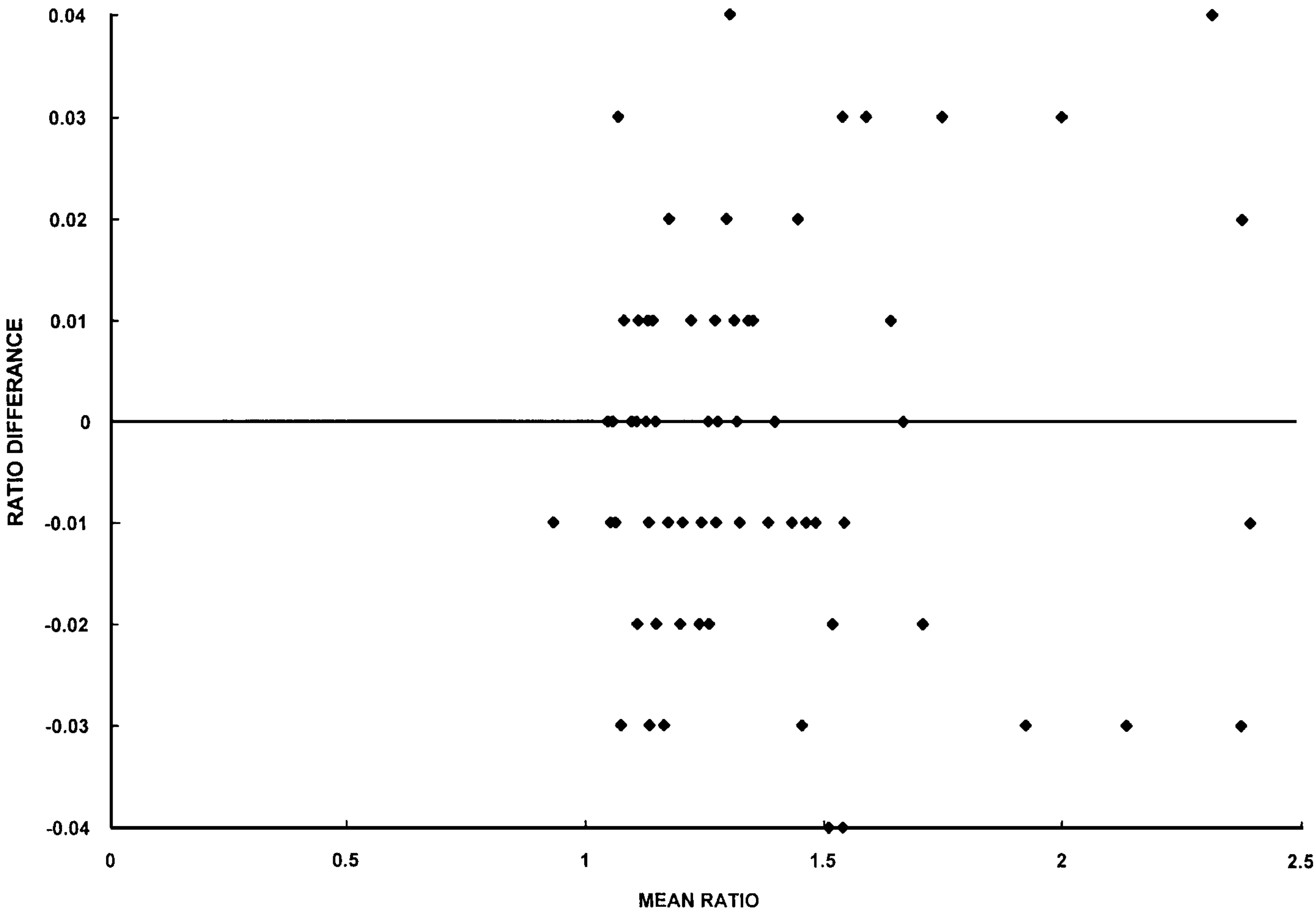

Figure 3. Bland–Altman plot for the three heart rate variability tests in 22 diabetic subjects

a wide range of simulated cardiac rhythms (29 types) from an ECG simulator (Laerdal Heartsim). Each rhythm was also combined with 60 Hz and simulated muscle noise at levels of –7 dB and –13 dB, respectively, with respect to the signal amplitude.

The 60 Hz noise was rejected effectively by the 6–28 Hz band pass filter and produced no measurable effect on the ANT performance. R-wave detection was reliable for all rhythms for R–R intervals up to 1.5 s, the maximum available. However, at this R–R interval, the addition of simulated muscle noise caused some false triggers. In the tests described above, heart rates as low as 34 beats per minute were detected without false triggers.

Conclusion

The autonomic neuropathy tester (ANT) provides rapid acquistion of R–R interval measurements for use in heart rate variability tests, eliminating the need for time-consuming visual interpretation of ECG charts. ANT measurements of R–R interval can be up to 10 times more accurate than manual measurements from ECG charts. The display of ANT heart rate measurements on a portable computer as a trend graph gives more reliable identification of maximum and minimum heart rate values for the calculation of heart rate variability ratios.

Detection of R-waves with the device is reliable for noise free signals. Poor signal to noise ratio is more likely to cause false triggering of the R-wave detector when the heart rate is low, but such events are easily excluded from data analysis by inspection of the heart rate trend display. The device has been used to carry out heart rate variability tests on over 70 subjects and provides convenient and consistent testing through the use of wrist electrodes and the provision of timing signals to the subject and operator.

Therefore, with the development of the ANT device there is now a reliable, reproducible and accurate method of assessing heart rate variability during a variety of clinical manoeuvres. This device is small, portable and non-invasive so should allow for the assessment of diabetic patients for autonomic neuropathy for research and, possibly, in the diabetic clinic setting.

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